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*Full Length Research Paper*

# Pre-plant weed control, optimum N rate and plant densities increase butternut (*Cucurbita moschata*) yield under smallholder irrigated conditions in the Eastern Cape Province of South Africa

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**Weed management is the most important limiting factor in butternut production by smallholder irrigation farmers in South Africa. Post-emergence chemical weed control options for butternut farms are very limited and often ineffective since most of the registered selective herbicides control annual grasses but not the broadleaf weeds. An on-farm experiment was therefore conducted to investigate the effects of pre-plant weed control (application or non-application of glyphosate to kill the first flush of weeds before planting), nitrogen (N) rate (60, 90, 120, 150 and 180 kg ha$^{-1}$) and plant density (10, 000, 20, 000 and 30, 000 plants ha$^{-1}$) on weed biomass and butternut yield. Pre-plant weed control resulted in a six-fold decrease in weed biomass, while increasing plant density from 10,000 to 30,000 plants ha$^{-1}$ decreased weed biomass by 47%. No marketable fruits were obtained when planting was done without prior weed control. Yield increased significantly with increase in plant density and the optimum density was estimated to be 25,000 plants ha$^{-1}$. Yield increased with N rate and the rate giving the highest marginal rate of return was 120 kg N ha$^{-1}$, which gave a yield of 26.7 t ha$^{-1}$. These findings suggest that pre-plant weed control, and use of optimum N rate and plant density are pre-requisites to successful butternut production.**

**Key words:** Pre-plant weed control, plant density, N rate, butternut yield.

## INTRODUCTION

Butternut (*Cucurbita moschata*) is an important summer crop grown by smallholder irrigation farmers in South Africa. Weed management has been identified as the most important limiting factor in the production of the crop in South Africa and elsewhere (Infante-Casella, 2003; Mossler and Nesheim, 2003; Department of Agriculture, 2005; Fanadzo, 2007; Fanadzo et al., 2010). The effect of weeds on the butternut crop is greatest during the period from emergence to the time before vine spreading (Mossler and Nesheim, 2003). Monitoring studies in Zanyokwe irrigation scheme in the Eastern Cape indicated that poor weed management led to poor crop stands and, in many cases, total abandonment of crops to weeds (Fanadzo, 2007; Fanadzo et al., 2010). The majority of farmers did not control weeds before planting and post-emergence weed control was inadequate, resulting in average butternut yields as low as 6 t ha$^{-1}$. This yield level is only 20 to 30% of the potential of 20 to 30 t ha$^{-1}$ attainable under irrigation, and indicates that an opportunity exists to improve yields in Zanyokwe irrigation scheme.

Post-emergence chemical weed control options for butternut are very limited since most of the registered selective herbicides control annual grasses but not the broadleaf weeds (Fournier and Brown, 1999; Kemble et al., 2000; Infante-Casella, 2003; Mossler and Nesheim,

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2003; Department of Agriculture, 2005). In South Africa, there are only three post-emergence herbicides registered for butternut, that is, cycloxydim (Focus Ultra®), propaquizafop (Agil 100®) and Haloxyfop-R methylester (Gallant Super® and Verdict Super®) (Department of Agriculture, 2004). Most post-emergence herbicides registered for use in butternut farms, including glyphosate, are non-selective and are applied with a shielded sprayer to control weeds in row middles (Mossler and Nesheim, 2003; Hochmuth et al., 2000).

Despite the limited post-emergence chemical weed control options, successful weed control in butternut farms is possible by integrating chemical and cultural techniques (PEIDAFA, 2005). Utilization of the stale seedbed technique is one of the viable options (Kemble et al., 2000; PEIDAFA, 2005; Bratsch, 2006; Finney and Creamer, 2008; Lanini, 2008). This technique consists of preparing a fine seedbed, allowing weeds to emerge, and directly removing weed seedlings via light cultivation or application of a non-selective herbicide just before planting. This technique helps provide an opportunity for crop emergence and growth before the next flush of weeds. Once the butternut crop has a starting advantage over the weeds, the broad, wide leaves of the vigorous plant compete with and help to suppress the late season weeds.

The stale seedbed technique, when used in combination with good plant stand, can help smother late season weeds, which are not as vigorous as those that emerge during the early part of the season. One strategy to reduce weed competition and optimize yield is to establish a good crop stand in which plants emerge and rapidly shade the ground, thereby smothering late-emerging weeds (Stall, 2006). Squashes have an extensive root system and can compete well with weeds for water and nutrients in the soil if well established. Establishment of higher plant populations is also helpful in reducing weed competition in butternut farms (Stall, 2006). Research indicates that increasing crop density can maximize the space occupied by the crop early in the season and put competitive pressure on weeds (Mohler, 2001; Finney and Creamer, 2008). In South Africa, squashes are generally grown at a plant density of 15,000 to 25,000 plants $ha^{-1}$ (Hygrotech SA, 2004), depending on vine size and target fruit size. However, monitoring studies in Zanyokwe irrigation scheme indicated that farmers commonly planted butternut at a target population of 10,000 plants $ha^{-1}$ (Fanadzo, 2007; Fanadzo et al., 2010). Higher populations would result in better weed control and higher yields. As already highlighted, full and rapid stand establishment is critical in butternut production, and early and adequate fertility can help achieve this. Optimum rates of nitrogen (N) fertilizer result in vigorously growing plants that can out-compete weeds and produce higher yields. In South Africa, the N rate recommendations for butternut vary from 80 to 120 kg $ha^{-1}$ (FSSA, 2007). However, monitoring studies conducted in Zanyokwe from 2005 to 2008 indicated that the average fertilizer rate applied to butternut was about 60 kg N $ha^{-1}$ (Fanadzo et al., 2010).

Intensive research on agronomic factors affecting productivity of summer squash has indicated that weed, fertilizer and population management are the most important (Mossler and Nesheim, 2003; Bratsch, 2006; Lanini, 2008; Stall, 2006). However, for winter squash and specifically butternut, there has been little work examining plant density, weed competition and their interaction with N, especially in South Africa. The objective of this study was to investigate the effects of pre-plant weed control, N rate and plant density on weed biomass and butternut yield.

## MATERIALS AND METHODS

### Trial site

The experiment was carried out at Bantubantu (32°45´S, 27°03´E) and Booi (32°46´S, 26°50´E) farms at Zanyokwe irrigation scheme in the Eastern Cape in the 2006/07 and 2007/08 summer seasons, respectively. Bantubantu has dark-coloured heavy-textured soils of the Valsrivier form while Booi has deep alluvials of the Oakleaf form, belonging to Jozini series (Soil Classification Working Group, 1991). The area has a warm temperate climate with mean annual rainfall of about 575 mm of which about 445 mm occurs in summer (van Averbeke et al., 1998). Due to low rainfall, crop production requires supplementary irrigation.

### Trial design and layout

The trial consisted of three factors; pre-plant weed control, N rate and plant density treatments laid out as a split-split plot in a randomized complete block design. Pre-plant weed control was the main plot, plant density the sub-plot and N rate the sub sub-plot treatment. Pre-plant weed control was at two levels; application or non application of glyphosate at a rate of 3 L $ha^{-1}$ to kill the first flush of weeds before planting, while plant density was at three levels; 10, 000, 20, 000 and 30, 000 plants $ha^{-1}$. In 2006/07 at Bantubantu farm, N rate was at three levels; 60, 120 and 180 kg $ha^{-1}$ but this was increased to five levels (60, 90, 120, 150 and 180 kg $ha^{-1}$) at Booi farm in 2007/08. The treatments were replicated three times at each site. Gross plots consisted of six rows, each 6 m long and spaced at 0.9 m between rows. The corresponding net plots consisted of the four middle rows, each 4 m long.

Land was ploughed and disked once using a tractor-drawn plough and disk harrow, respectively, before the plots were marked. Three seeds of butternut cultivar Waltham purchased from Hygrotech SA (Pty) Ltd were sown in planting holes at a depth of 2 - 3 cm and later thinned to one plant per planting station at 2 weeks after emergence (WAE). The variety was chosen as it is the most commonly used in the country. Waltham is a vining winter squash that reaches maturity in 85 – 90 days after emergence and has a yield potential of 20 to 30 t $ha^{-1}$. Half of the N was applied at planting while the other half was applied prior to flowering at 3 WAE. All plots were weeded once at 2 WAE using hand hoeing, as is common practice in the irrigation scheme. Supplementary irrigation was done using the sprinkler system with a gross application of 6 mm $h^{-1}$. Irrigation water was applied to meet the crop water requirements and the amount applied varied with weather conditions and crop growth stage (Table 1).

Prior to weeding at 2 WAE, weed biomass was assessed by throwing three 30 cm × 30 cm quadrants into the net plots and

**Table 1.** Rainfall received, irrigation water supplied and mean diurnal temperatures during growth of butternut at Bantubantu (2006/07) and Booi (2007/08) farms.

| Month | 2006/07 (mm) | | | 2007/08 (mm) | | | Temperature (°C) | |
|---|---|---|---|---|---|---|---|---|
| | Rainfall | Irrigation | Total | Rainfall | Irrigation | Total | 2006/07 | 2007/08 |
| December | 97.0 | 59.0 | 156.0 | 124.7 | 36.0 | 160.7 | 20.0 | 21.6 |
| January | 18.0 | 64.0 | 82.0 | 104.7 | 36.0 | 140.7 | 22.8 | 22.1 |
| February | 102.0 | 122.0 | 224.0 | 96.5 | 36.0 | 132.5 | 23.2 | 22.6 |
| March | 64.0 | 0.0 | 64.0 | 65.2 | 0.0 | 65.2 | 20.0 | 20.8 |
| Total | 295.0 | 245.0 | 540.0 | 391.1 | 108.0 | 499.1 | - | - |

**Table 2.** Weed biomass (g $m^{-2}$) in butternut farms with and without pre-plant weed control at Bantubantu and Booi farms.

| Pre-plant weed control | 2 WAE | | Harvesting | |
|---|---|---|---|---|
| | Bantubantu | Booi | Bantubantu | Booi |
| No | 41.5 | 153.6 | 663.6 | 1,194.0 |
| Yes | 6.8 | 25.4 | 127.2 | 383.6 |
| LSD(0.05) | 9.5 | 77.5 | 36.4 | 109.9 |

cutting the weeds at ground level. The weeds were collected in paper bags, oven dried to a constant weight at 80°C and weighed. At harvesting, weed biomass was assessed as at 2 WAE. Fruit weight, marketable and total butternut yield was recorded. Market size butternut was considered as those fruits weighing 0.6 kg or more. Weed biomass, marketable and total yield, and average fruit weight were subjected to analysis of variance (ANOVA). ANOVA was performed using Genstat Release 7.22 DE on a per site basis and Bartlett's test (Gomez and Gomez, 1984) carried out to test the homogeneity of error variances before combining across sites. Marginal analysis was used to calculate the marginal rate of return (MRR) in switching from 60 kg N $ha^{-1}$ to higher N rates (Evans, 2008).

## RESULTS

### Weed biomass

Bartlett's test showed heterogeneity of error variances for weed biomass for the two sites and therefore the weed biomass data is presented separately for Bantubantu and Booi farms. There were no significant interactions among factors on weed biomass at both sites. Pre-plant weed control treatments had significant ($p < 0.01$) effects on weed biomass obtained at 2 WAE and at harvesting at both sites. Plant density had no significant effects on weed biomass at 2 WAE at both sites. However, at harvesting, plant density had a significant effect ($p < 0.01$) on weed biomass at Bantubantu, but not at Booi. N rate had no significant effects on weed biomass obtained both at 2 WAE and at harvesting at both sites. At both sites, there was a consistent decrease in weed biomass at 2 WAE and crop harvesting with herbicide application prior to planting.

At harvesting, weed biomass decreased from 129.4 to 88.2 g $m^{-2}$ when plant density was increased from 10,000 to 30,000 plants $ha^{-1}$ at Bantubantu (Table 2).

### Marketable yield

Bartlett's test showed homogeneity of error variances for the two sites on marketable and total yield; therefore, the data from the two sites were combined for analysis. There was a significant ($p < 0.01$) pre-plant weed control × plant density × N rate interaction. There were also significant ($p < 0.01$) site × pre-plant weed control, pre-plant weed control × N rate, pre-plant weed control × plant density and N rate × plant density interactions. All main effects were significant ($p < 0.01$). The three-way interaction showed that no marketable yield was obtained when planting was done without prior weed control regardless of N rate and plant density (Table 3). With pre-plant weed control, yield increased with increased N rate. Growing butternut at 10,000 plants $ha^{-1}$ resulted in the least yield regardless of N rate. At 60 and 120 kg N $ha^{-1}$, the density of 30,000 plants $ha^{-1}$ yielded lower than 20,000 plants $ha^{-1}$ while the opposite was true at 180 kg N $ha^{-1}$ (Table 3).

With regard to site × pre-plant weed control interaction; no marketable fruits were obtained when there was no pre-plant weed control at both sites. When weeds were controlled prior to planting, Booi produced 5 321 kg $ha^{-1}$ more marketable yield than Bantubantu, which produced 20 876 kg $ha^{-1}$. With regard to pre-plant weed control × N rate interaction, no marketable fruits were obtained when no weed control was executed before planting regardless of N rate. However, with pre-plant weed control,

**Table 3.** Marketable yield (kg ha$^{-1}$) of butternut obtained with and without pre-plant weed control and at varying levels of N rate and plant density at Bantubantu and Booi farms.

| Pre-plant weed control | N rate (kg ha$^{-1}$) | Plant density (plants ha$^{-1}$) | | |
|---|---|---|---|---|
| | | 10,000 | 20,000 | 30,000 |
| No | 60 | 0 | 0 | 0 |
| | 120 | 0 | 0 | 0 |
| | 180 | 0 | 0 | 0 |
| Yes | 60 | 18,833 | 20,732 | 20,458 |
| | 120 | 22,178 | 25,355 | 25,221 |
| | 180 | 23,913 | 27,327 | 27,815 |
| LSD(0.05) | | 90.6 | | |

**Table 4.** Marginal rate of return of switching from 60 kg N ha$^{-1}$ to higher N rates in butternut production at Zanyokwe irrigation scheme.

| Parameter | N rate (kg ha$^{-1}$) | | | | |
|---|---|---|---|---|---|
| | 60 | 90 | 120 | 150 | 180 |
| **Net benefits** | | | | | |
| Average yield (kg ha$^{-1}$) | 23,083 | 24,820 | 26,708 | 27,906 | 28,856 |
| Adjusted yield (kg ha$^{-1}$)[a] | 20,775 | 22,338 | 24,037 | 25,115 | 25,970 |
| Gross field benefits (ZAR ha$^{-1}$) | 31,162.50 | 33,507.00 | 36,055.50 | 37,672.50 | 38, 955.00 |
| Cost of fertiliser (ZAR ha$^{-1}$) | 1,939.27 | 2,908.90 | 3,878.53 | 4,848.16 | 5,817.81 |
| Total Variable costs (ZAR ha$^{-1}$) | 1,939.27 | 2,908.90 | 3,878.53 | 4,848.16 | 5,817.81 |
| Net benefits (ZAR ha$^{-1}$) | 29,223.23 | 30,598.10 | 32,176.97 | 32,824.34 | 33,137.19 |
| MRR between technologies | | | | | |
| ZAR per switch | - | 1,374.87 | 1 578.87 | 647.37 | 312.85 |
| Percent (%) | - | 142 | 163 | 67 | 32 |

[a]Average yield was adjusted by 10% to give the adjusted yield.

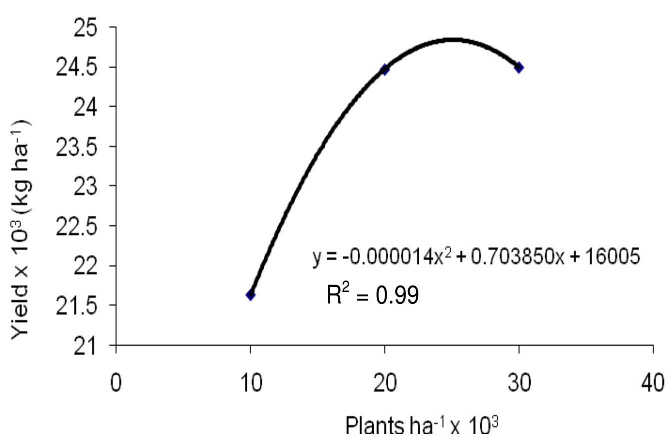


**Figure 1.** Butternut marketable yield response to plant density with pre-plant weed control using glyphosate.

marketable yield increased with N rate from 20 007 kg ha$^{-1}$ at 60 kg N ha$^{-1}$ to 24 252 and 26 351 kg ha$^{-1}$ when N rate was increased to 120 and 180 kg ha$^{-1}$, respectively. The MRR to additional N was calculated using data from Booi farm which had more levels of N and this would be applicable to Bantubantu farm because of the significant ($p < 0.01$) increase in yield with increase in N rate. At this site, all fruits obtained with pre-plant weed control were of marketable size, thus, marketable yield was equal to total yield. Increasing N rate from 60 to 90 kg ha$^{-1}$ resulted in a MRR of 142%. MRR increased to 163% when N rate was increased to 120 kg ha$^{-1}$, but decreased to 67 and 32% when N rate was increased to 150 and 180 kg ha$^{-1}$, respectively (Table 4).

Regardless of plant density, failure to control weeds before planting resulted in unmarketable fruits. With pre-plant weed control, 10, 000 plants ha$^{-1}$ resulted in the least yield while 20,000 and 30,000 plants ha$^{-1}$ produced higher yields of 24,472 and 24,498 kg ha$^{-1}$, which were not significantly different. The relationship between marketable yield and population showed a significant quadratic response with an estimated optimum plant density of 25,138 plants ha$^{-1}$ (Figure 1).

**Table 5.** Total butternut yield obtained with and without pre-plant weed control, and at varying levels of N rate and plant density at Zanyokwe irrigation scheme.

| Pre-plant Weed control | N rate ($kg\ ha^{-1}$) | Total yield ($kg\ ha^{-1}$) 10,000 plants $ha^{-1}$ | 20,000 plants $ha^{-1}$ | 30,000 plants $ha^{-1}$ |
|---|---|---|---|---|
| | 60 | 558 | 555 | 562 |
| No | 120 | 555 | 555 | 572 |
| | 180 | 553 | 565 | 573 |
| | 60 | 19,398 | 21,130 | 20,350 |
| Yes | 120 | 23,310 | 25,773 | 25,885 |
| | 180 | 24,048 | 27,752 | 28,485 |
| LSD (0.05) | | | 473 | |

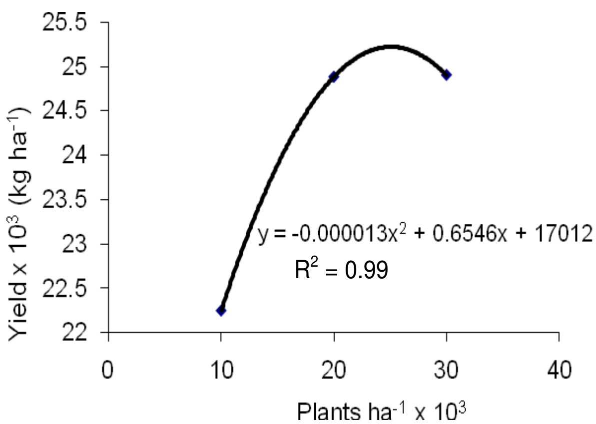


**Figure 2.** Total butternut yield response to population density with pre-plant weed control using glyphosate.

## Total yield

There was a significant ($p < 0.05$) pre-plant weed control × plant density × N rate interaction on total yield. There were also significant ($p < 0.01$) site × pre-plant weed control pre-plant weed control × N rate, pre-plant weed control × plant density and N rate × plant density interactions. All the main effects were significant ($p < 0.01$). The three-way interaction showed that yield was significantly lower when planting was done without prior weed control; regardless of plant density and N rate (Table 5). When weeds were controlled before planting, the lowest plant density (10,000 plants $ha^{-1}$) resulted in the least yield regardless of N rate. At 60 kg N $ha^{-1}$ a density of 20,000 plants $ha^{-1}$ resulted in higher yield than 30,000 plants $ha^{-1}$, but at 180 kg N $ha^{-1}$ 30,000 plants $ha^{-1}$ yielded higher than 20,000 plants $ha^{-1}$. At 120 kg N $ha^{-1}$, there was no difference in yield between 20,000 and 30,000 plants $ha^{-1}$ densities (Table 5).

With respect to the site x pre-plant weed control interaction, no yield was obtained at Booi without pre-plant weed control while Bantubantu yielded 1,122 kg $ha^{-1}$. With pre-plant weed control, Booi yielded 4,404 kg $ha^{-1}$ higher than Bantubantu, which yielded 21,813 kg $ha^{-1}$. With respect to pre-plant weed control × N rate interaction there was no significant difference in yield regardless of N rate when no pre-plant weed control was done. With pre-plant weed control, yield increased with increase in N rate from 20,293 kg $ha^{-1}$ at 60 kg N $ha^{-1}$ to 24,989 and 26 762 kg $ha^{-1}$ when N rate was increased to 120 and 180 kg $ha^{-1}$, respectively.

With regard to the pre-plant weed control × plant density interaction, yields were similar (556, 558 and 569 kg $ha^{-1}$ for the 10,000, 20,000 and 30,000 plants $ha^{-1}$ densities) when no pre-plant weed control was exercised. With pre-plant weed control, there were significant differences in yield with plant density. The least yield of 22,252 kg $ha^{-1}$ was achieved at 10,000 plants $ha^{-1}$ while at 20,000 and 30,000 plants $ha^{-1}$ treatments, similar but significantly higher yields of 24,885 and 24,907 kg $ha^{-1}$, respectively, were obtained. The response of yield to population indicated a significant quadratic response ($p < 0.01$) with an estimated optimum plant density of 25,177 plants $ha^{-1}$ (Figure 2).

## Average fruit size

Bartlett's test showed heterogeneity of error variances for fruit size and therefore data are presented separately for the two sites. At Bantubantu there were significant ($p < 0.01$) pre-plant weed control × N rate and pre-plant weed control × plant density interactions on average fruit size. All the main effects were significant ($p < 0.01$). With respect to pre-plant weed control × N rate interaction, average fruit size with no pre-plant weed control was similar whilst there was a significant increase in average fruit size with increase in N rate when weeds were controlled prior to planting (Table 6).

With respect to pre-plant weed control × plant density interaction, failure to control weeds prior to planting resulted in similar and smaller fruits regardless of plant density. With pre-plant weed control, average fruit size obtained from 20,000 and 30,000 plants $ha^{-1}$ was similar but significantly ($p < 0.01$) smaller than that at 10,000 plants $ha^{-1}$ (Table 7).

At Booi farm, the pre-plant weed control × plant density

**Table 6.** Average butternut fruit size with and without pre-plant weed control and at varying N rate at Bantubantu farm.

| Pre-plant weed control | Weight per fruit (kg) | | |
|---|---|---|---|
| | 60 kg N ha$^{-1}$ | 120 kg N ha$^{-1}$ | 180 kg N ha$^{-1}$ |
| No | 0.23 | 0.24 | 0.28 |
| Yes | 1.20 | 1.46 | 1.59 |
| LSD (0.05) | | 0.12 | |

**Table 7.** Butternut fruit size with and without pre-plant weed control, and at varying plant density at Bantubantu farm.

| Pre-plant weed control | Weight per fruit (kg) | | |
|---|---|---|---|
| | 10,000 plants ha$^{-1}$ | 20,000 plants ha$^{-1}$ | 30,000 plants ha$^{-1}$ |
| No | 0.24 | 0.24 | 0.26 |
| Yes | 1.21 | 1.07 | 0.98 |
| LSD(0.05) | | 0.12 | |

**Table 8.** Butternut fruit size at varying N rates and plant population densities and with pre-plant weed control using glyphosate at Booi farm.

| N rate (kg ha$^{-1}$) | Weight per fruit (kg) | | |
|---|---|---|---|
| | 10,000 plants ha$^{-1}$ | 20,000 plants ha$^{-1}$ | 30,000 plants ha$^{-1}$ |
| 60 | 0.93 | 0.92 | 0.88 |
| 90 | 1.18 | 1.04 | 0.89 |
| 120 | 1.22 | 1.09 | 0.93 |
| 150 | 1.35 | 1.12 | 1.06 |
| 180 | 1.40 | 1.18 | 1.12 |
| LSD(0.05) | | 0.03 | |

× N rate interaction was significant ($p < 0.01$). There were significant ($p < 0.01$) pre-plant weed control × N rate, pre-plant weed control × plant density and N rate × plant density interactions on average fruit size. Since no fruits were obtained when planting was done without prior weed control at Booi farm, description of results will focus on the interaction between population and N rate with pre-plant weed control. At 60 kg N ha$^{-1}$, similar size fruits were obtained at 10,000 and 20,000 plants ha$^{-1}$ while the 30,000 plants ha$^{-1}$ density level produced significantly ($p < 0.01$) smaller fruits. At the higher N rates there was a significant ($p < 0.01$) decrease in average fruit size with increase in plant density (Table 8).

## DISCUSSION

Results of this study indicated a significant reduction in weed biomass with application of a pre-plant herbicide to kill the first flush of weeds before planting butternut. Weed biomass (dry weight), rather than weed density, was used as a measure of the effect of treatments on weed growth since such values combine weed density and size. Despite the limited post-emergence chemical weed control options for butternut, successful weed control is possible by employing integrated weed management techniques (PEIDAFA, 2005). Application of non-selective herbicide before planting is a technique that can be used by farmers as part of integrated weed management to give the crop a competitive advantage in the early growth stages before the plants start to produce vines.

Plant density had no effect of weed biomass at 2 WAE most probably because at 2 WAE the vines had not started to spread. This period from emergence to the time before vine spreading is the most critical for weed control in butternut squash. The decrease in weed biomass with increase in plant density, as observed at crop harvest, was a result of earlier and more complete ground cover, which resulted in increased efficiency in smothering weeds. Full and rapid stand establishment is critical in butternut production, and early fertility and irrigation can help achieve this (Bratsch, 2006). According to Lanini (2008), the vigorous and rapid growth of squash during the warm season makes them very competitive to the weeds such that a single cultivation may be all that is needed for weed control.

N rate had no effect on weed biomass partly because of the banding method of application employed. Band application of fertilizer, as opposed to broadcasting, tends to reduce early weed growth between rows. Banding reduces weed competition and places the fertilizer where the crop will reach it quickly (Bratsch, 2006). Banding is the method of fertilizer application used by the Zanyokwe irrigation scheme farmers and is encouraged from a weed management point of view.

The reduction in both marketable and total butternut yield without pre-plant weed control was a result of increased weed-crop competition within the first 2 WAE as shown by increased weed biomass. Reduction in yield may be attributable to competition for photosynthetically active radiation, nutrients and water (Berry et al., 2001). Reduction of marketable yield to zero might have been caused by the fact that the effect of weed competition on the squash plant is greatest early in the season, at which time weed management is most critical (Mossler and Nesheim, 2003). These results are in conformity with findings of Terry et al. (1997) of a 100% reduction in muskmelon (*Cucumis melo* L. var. *reticulates*) and watermelon (*Citrullus lanatus* L.) yield due to weeds. They attributed the yield reduction to shading because the weeds grew faster and shaded the low-growing crops. Berry et al. (2001) reported that weeds could cause a 10% yield loss in watermelon if allowed to compete for only 3 - 4 days early in the season. In this study, the pre-plant herbicide resulted in less competition from weeds, enabling plants to grow more vigorously and quickly, thereby out-competing late season weeds. On the other hand, failure to control weeds prior to planting meant that crop-weed competition went on unabated for the first 2 weeks after crop emergence.

The fact that 10,000 plants ha$^{-1}$ yielded the least suggests that this plant density, as commonly used by the farmers at Zanyokwe, is too low. The optimum population to maximize yield under the conditions of the experiments was estimated to be about 25,000 plants ha$^{-1}$, which is nearly out of the recommendation limit of 15,000 to 25,000 plants ha$^{-1}$ for South Africa (Hygrotech SA, 2004). This might suggest the need for revisiting the recommendation limits for butternut production under irrigation. The decrease in average fruit size with higher population densities as observed in this study is in conformity with other findings (Sanders et al., 1999; Motsenbocker and Arancibia, 2002). The increased number of fruits per unit area is probably the yield component that contributes most to greater yield under high plant density as noted by NeSmith (1993) and Duthie et al. (1999). In this study, the greater fruit number per hectare compensated for the smaller fruit size at higher population densities, resulting in a significant increase in yield. The maximum yield of 28.9 t ha$^{-1}$ obtained when fertilizer was applied at 180 kg N ha$^{-1}$ at 20,000 or 30,000 plants ha$^{-1}$ is within the 20 to 30 t ha$^{-1}$ yield potential in commercial production in South Africa. This indicates that the conditions in the study were similar to those experienced in commercial fields. Thus, information generated from this study could also be applicable to commercial butternut farms.

Increasing the rate of N fertilisation in cucurbits has generally been reported to increase yields (Reiners and Riggs, 1997). Increase in yield with increased rate of N in this study was partly a result of bigger size fruits obtained at the higher N rates. Similar findings of a positive response of butternut yield to increased N rate have been reported. Dweikat and Kostewicz (1989) reported that the yield of zucchini squash (*Cucurbita pepo* var. *melopepo* L.) increased as the N rate rose from 67 to 202 kg ha$^{-1}$, but decreased above this maximum. Similarly, high N levels significantly increased yields of watermelons in Florida (Reiners and Riggs, 1997). Sweaider et al. (1988) reported that higher N rates had a greater effect on yield when combined with irrigation.

The average butternut yield of about 6 t ha$^{-1}$ achieved by farmers in Zanyokwe irrigation scheme (Fanadzo et al., 2010) is about 21% of the optimum yield obtained in this study. From the results of economic analysis, the best N rate to use is 120 kg ha$^{-1}$ since this resulted in the highest MRR of 163%. This is based on the assumption that the minimum acceptable rate of return (MARR) is 100% (Evans, 2008). The N rate of 120 kg ha$^{-1}$ is also the highest rate recommended by the Fertilizer Society of South Africa (FSSA, 2007).

## Conclusions

This study demonstrated the importance of proper agronomic practices in maximizing butternut yields and profits. Use of the stale seedbed technique through pre-plant weed control to kill early season weeds is a prerequisite to successful butternut production. To optimize yield, plant density should be increased from farmer practice of 10,000 plants ha$^{-1}$ to 25 000 plants ha$^{-1}$ while doubling N rate of farmer practice from 60 to 120 kg N ha$^{-1}$ will result in maximum returns. This study demonstrates that the low yields obtained by farmers may be attributed to poor weed control, nutrient deficiency and low population densities. Of the three factors, pre-plant weed control is the most important factor as it resulted in 100% marketable yield reduction when not executed.

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